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SELECTIVE APPLICATION OF ADVANCED BIOTECHNOLOGY FOR DEVELOPING COUNTRIES*

prepared by

Carl-Göran Hedén**

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** Professor, Karolinska Institutet, Stockholm, Sweden.

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A. BACKGROUND AND JUSTIFICATION

Modern developments in fermentation technology have deep roots in ancient food technologies that improved the keeping qualities of many perishable products at the same time as they upgraded their taste, digestibility and nutritional value. The early methods for making beer, bread, wine and cheese paved the way for modern bioengineering which now provides the basis for the production of vaccines and other drugs, chemicals, biofertilizers, etc. However, when industrial operations replaced the household practices, pure cultures took over from the natural mixed populations, and the general approach to the practices in fermentation changed. Not only were wooden caskets and concrete or clay vats replaced by stirred stainless-steel reactors, but large-scale production also called for efficient heat exchangers, valves, pipes and many other devices that were not needed for small-scale operations.

The economic consequences of spoiling big batches due to erratic processes also made it necessary to refine the techniques and to set up control laboratories which provided a basis for practically oriented research and development efforts. This tended to emphasize the exploitation of the economy of scale. The optimization of the material inputs and the effective use of instrumentation gradually reduced the labour requirements so that the fermentation industry must now be grouped with "high technology" production processes.

At the same time it must be realized that an internationally competitive production of antibiotics, single-cell protein and many industrial chemicals is now almost unthinkable in anything but very large, modern facilities; it should also be noted that many developing countries have selective advantages that are not fully utilized for lack of appropriate biotechnologies making full use of the recent advances in microbial genetics and bioengineering. Those countries, for instance, often have a great potential for carbohydrate production, cheap labour is available and there is often legislation to guide the industrialization process.

Needless to say, the developing countries will benefit from an indigenous competence making it possible not only to develop methods adapted to their unique opportunities but also to choose equipment and processes from a rapidly expanding international market.

In developing a work plan for the Department for Advanced Biotechnology of the ICGEB there should obviously be a research thrust towards new, simplified biotechnologies - "biodevelopment engineering", for short. However, the department should also have a service function in relation to the other departments and a capacity for training bioengineers so they are well versed in handling advanced equipment for the optimized production of enzymes, drugs, nutrients, etc. Consequently the work plan must be geared to a dual responsibility: research in the field of "biodevelopment engineering" and a service and training function in what might be called "advanced biotechnology".

Almost by definition "biodevelopment engineering" must be field-oriented and transdisciplinary in character. It lends itself to a broadened outlook in fields such as materials science, environmental chemistry and food technology. However, the centre of gravity should be in those areas of applied microbiology which are likely to be of direct relevance to employment generation and rural development. This means that effective methods for small-scale production will be developed and that the technical requirements for the support of such activities will be explored in practice. For instance, the applicability of the "dispersed factory principle" will be studied. Questions would be asked such as: "How can well-controlled starter cultures be produced and distributed to ensure vigorous and safe fermentations in simple equipment?" and "Can immobilized thermophilic strains offer new approaches for village-level fermentations?"

In the selection of research topics suitable for joint efforts at the central facilities of ICGEB, there will certainly be an emphasis on those activities that are not stimulated by conventional "market forces" - either because the potential buyers of a new product are poor, or because a new method would satisfy needs that are only felt in peripheral rural settlements.

ICGEB can also be expected to develop a unique profile in certain segments of the research front. The Centre is for instance likely to strive for excellence in the application of microbial ecology to the design of mixed fermentations that will permit unsterile operations. Such a focus would be more natural at ICGEB than in laboratories where the steam-sterilized stainless steel fermenter is the laboratory centre piece.

The other development objectives of ICGEB, that of providing a service function to the other departments and that of providing a basis for training, must also have a research component, if the goal of fostering internationally competitive bioengineers is to be reached. The emphasis of this component will depend largely on the calibre and specialization of the staff, and the details can consequently not be outlined at this stage. It is, however, obvious that areas such as computer-aided process design, sensor development, energy analysis and mass-transfer theory would all be of relevance.

B. ACTIVITIES

The advanced biotechnology work programme will consist of two distinct types of activities; the field activities carried out through the Biological Resource Development Teams (BIORED) and the research and development programmes carried out at the Centre, including those involving pilot plant studies for the scaling up of processes studied in other work programmes at the Centre.

BIORED

BIOREDs are multidisciplinary teams of local scientists connected to national laboratories of microbiology or the like. Their prior function will be to identify local resources for commercial exploitation and conduct field experiments to explore and develop local biotechnology applications. The role of ICGEB in relation to BIORED will be to promote the development of such teams and provide initial advice and assistance so as to demonstrate the value of this concept for decentralized local applications.

The BIORED will be provided with transportable laboratory equipment for process microbiology, including some basic upstream and downstream equipment for the preparation of raw materials and product recovery in addition to standard fermenters.

A standardized mobile unit would not only serve the extension functions mentioned, but would also permit the testing of novel equipment designed for village use. In addition, it would permit an evaluation of various perishable materials and the suitability of local water resources as a medium base.

This equipment should be designed for flexibility and should be mobile so that it can be assigned to different research and training institutions from which the team could draw laboratory support and facilities for local training courses.

Initially the base laboratories might be chosen among the "Microbiological Resource Centres" (MIRCENs) established by United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO) and International Cell Research Organization (ICRO). They are well co-ordinated and have hosted a number of training courses.

The BIOREDs will be staffed with personnel from the local institute and the operational expenses will be financed by the country hosting the BIORED.

The BIORED missions could well be divided into three four-months periods.

In the first laboratory phase, the unit would work in direct association with a selected base laboratory where local personnel would be trained for field activities.

In the following field phase, the mobile unit would operate in a rural community, or some other suitable target location.

Thirdly, in a technology transfer phase, the unit would assist in the building of suitable facilities and in the starting of processes appropriate to local needs and resources. Some of the core material might well then have to be left behind, but this could be easily be replaced before a new mission is undertaken.

No new mission should start until it is reasonably sure that the base laboratory is capable of providing continued support to the field activities. This technical support ought to be coupled with a socioeconomic impact study. This could provide the basis for social innovations that would help to generate self-reliance (preferential loan systems, marketing contracts, co-operative arrangements, etc.)

In addition to the practical training carried out by the BIOREDs, regional courses will be offered covering a wide range of topics such as fermentation technology, separation processes, etc.

The regional courses would be associated with the initial phase of BIORED operations at a selected base laboratory. This would provide the setting for organized laboratory exercises geared to regional needs, but the practical work would be supported by overview lectures on the state of the art in fermentation technology. The aim of the courses would be to plant the seeds for an indigenous competence ranging from the capacity to evaluate and improve traditional food fermentations to the design of novel equipment based on the experience gained from participation in the BIORED field operations.

Advanced biotechnology and pilot plant

Just as the field activities would be supported by the base laboratory, the latter would be supported by ICGEB. The Centre should not only be capable of trouble-shooting beyong the capacity of the base laboratory, but it would also develop new, simplified biotechnologies, i.e. provide international leadership in "biodevelopment engineering". Since the selection of topics would be guided by the research priorities defined by the scientific board and eventual feedback of BIOREDs, it would be premature to define specific research topics in the current draft work plan. Consequently, the six topics listed below have been selected for their potential to stimulate international co-operation and have fairly general interest:

1. A cheap and simple mycotoxin test for field use. Fungi that produce toxic substances in moist grain, peanuts and other economically important crops are common in the humid tropics, and indigenous fermented foods have also been implicated in occasional episodes of poisoning. Cheap, broad-spectrum detection kits for mycotoxins would therefore be of value for demonstrating the inadequacy of many harvesting, transport, drying and storage procedures. Such kits would also be useful in the search for detoxification methods based on fermentation principles.

2. A microbiological method to release cellulose fibres so that they can be used for small-scale paper manufacturing. It has been demonstrated that mutants of certain fungi that have lost their capacity to decompose cellulose can still attack lignin (7). The process is slow but might be accelerated through the application of genetic engineering and might, under all circumstances, offer a microbiological route to small-scale paper manufacturing where the ambient temperature is high and large containers for wood chips can be built cheaply.

3. An effective system for the production and distribution of mycorrhizae and biological nitrogen fixers that can be used in afforestation. It has been demonstrated that afforestation of arid environments can be supported by inoculation with mycorrhizae and that nitrogen-fixing microorganisms can also be put to use in forestry. However, mycorrhiza spores are difficult to produce in significant quantities, and reliable and cheap carrier materials for the distribution of various inoculants are needed.

4. A protected fermentation to propagate B. thuringiensis under primitive conditions, for use as an insecticide. Flies constitute a health hazard in many rural communities and, even if emphasis must be given to the hygienic upgrading of the environment, a biological insecticide of proven efficacy and safety might be a useful adjunct.

5. A fermentation method to preserve and upgrade leaf protein so that it can be used as a baby food. It is now well known that the leaf protein, which can be pressed out of many plants, is often of excellent nutritive qualitiy. However, it is a perishable material that might need to be preserved. An interesting approach is then to use fermentation with lactobacilli (8), a process which might become part of systems designed to utilize the biomass from every part of the plant. Almost all components of such systems (effective lactic acid production, bioconversion of lignocellulosic residues, fermentative upgrading of the juices left after protein removal) could benefit from genetic engineering.

6. Thermophilic cellulase producer(s) for small-scale use in the production of liquid fuels. Thermophilic cellulase producers are of particular interest because they can be used in "unsterile" fermentations that are suitable for warm climates where they require little or no water cooling. If, in addition, they themselves, or in conjunction with other

thermophilic microorganisms, can convert the glucose produced into alcohol (or other volatiles) a subsequent distillation process for liquid fuels would require less energy.

This activity is considered complementary to those under the work programme on the "Application of Genetic Engineering for Energy and Fertilizer Production from Biomass".[1/]

Research targets such as those mentioned above would pave the way for co-operation with the other research projects. Advanced labelling techniques and monoclonal antibody techniques would for instance be natural components of item 1, genetic engineering of 2 and 6, and microbial physiology of 3,4 and 5.

These research targets listed here might also trigger international co-operation beyond ICGEB and its associated institutions. An exchange of strains with the MIRCEN laboratories (1) might for instance contribute significantly to success with project 3, and international screening for thermophilic cellulase producers could be an important component of project 6.

However, as mentioned earlier, the advanced biotechnology programme would also provide a service function to the other work programmes which would often require quantities of specialized enzymes, antigens, and other fine chemicals that would call for large-scale production runs. Those would be performed according to advanced bioengineering principles and would thus introduce visiting scientists to a "competitive fermentation technology" that makes full use of modern optimization techniques and computer aids. A likely focus would be on such restriction enzymes and advanced reagents as a young scientist might need after returning to his home country.

The Centre needs facilities for large-scale work and supporting work shop facilities in view of two critically important functions:

(a) To provide adequate quantities of important organic materials to the various departments and other research laboratories engaged in genetic engineering and biotechnology but lacking facilities for preparatory work. This service would be provided on a pure cost basis (man hours, chemicals and basic services such as steam and electricity) but without regard to the capital investment in the equipment;

1/See ID/WG.382/2/Add.2

(b) To provide for scale-up experiments on novel products and processes and to give a setting for training in modern bioengineering practices (fed-batch fermentations, feedback control based on head-space analysis and calorimetry, data logging and computer-assisted optimization, etc.)

Considering the variety of projects that might require support, the pilot plant would have to be designed for a very high degree of flexibility. It would be split into three separate sections. One would maintain the heavy equipment (air compressors, steam generator, auxiliary power supply and refrigeration system) along with three fermenters (100, 1000 and 5000 litres) of the standard common in the antibiotics industry.

The second section would be a safety facility with air locks, exhaust gas filtration, effluent and overflow sterilization, steam seals or magnetic transmissions for rotating shafts, special alarms for malfunctions, etc. This facility would also have three big fermenters (100, 500 and 1000 litres). In addition it would have a closed system for harvesting and cell disruption, so that enzymes and antigens could be extracted from pathogens.

The main function would, however, be to perform scaling-up experiments on genetically manipulated microorganisms.

The third section would service the two others with a combined gas chromatograph-mass spectrometer, oxygen and carbon dioxide analyzers for the control of pH, temperature, aeration, stirrer speed, etc. in the various fermenters, all of which could be put under computer control.

In addition to the experience and know-how obtained by participating in the above-mentioned activities, the trainees will complete their education through formal courses.

The central courses would be aimed at methods suitable for the preparation of various important enzymes and other biochemical materials used in genetic engineering and applications of enzyme technology. (A more detailed description of the formal education in biochemical engineering is provided in Annex II) The exercises would be based on a laboratory manual that would be subject to continuous upgrading on the basis of the feedback from participants in earlier sessions and on new data that is published.

The laboratory manual would be divided into four parts:

A. laboratory hygiene and safety;
B. strain maintenance and control;
C. production techniques; and
D. separation and purification methods.

Its preparation and updating would be the responsibility of a permanent joint committee with participation from all departments. The result should be a useful manual for in-house use but also a loose-leaf handbook that would help to keep all associated laboratories and the ICGEB alumni up to date with regard to modern preparatory methods.

Once a year, the work programme would organize a small meeting for a project review group of experts. This meeting would cover important technical developments relevant to the activities of the department. Participating governments would be invited to send observers to this meeting, which should be designed as a seminar that would provide an overview of the fermentation field, including important patents and licensing agreements. The papers presented at the seminar and a summary of the discussions would be distributed to ICGEB alumni and participating governments as a series entitled "Bioengineering for Development".

C. WORK PLAN

Year 1:

- Planning of facilities and establishment of research priorities by the Board of Scientific Directors in consultation with a project review group;
- Design of pilot plant;
- Design of model BIORED unit (No. 1).

Year 2:

- Testing of pilot plant equipment;
- Establishment and assignment of BIORED Unit 1;
- Negotiations about BIORED Units 2 and 3;
- Preparation of laboratory manual;
- First central course.

Year 3:

- BIORED Unit 1 operates in location A;
- BIORED Units 2 and 3 built and assigned;
- First regional course at location A;
- First expert meeting and seminar;
- Second central course.

Year 4:

- BIORED Unit 1 operates in location B;
- BIORED Units 2 and 3 operate in locations C and D;
- Negotiations about BIORED Units 4 and 5;
- Regional courses at locations B,C, and D;
- Third central course.

Year 5:

- BIORED Unit 1 operates in location E;
- BIORED Units 2 and 3 operate in locations F and G;
- BIORED Units 4 and 5 built and assigned to locations H and I;
- Regional courses at locations E,F.G,H and I;
- Second expert meeting and seminar;
- Fourth central course;
- Evaluation performed by project review group.

D. PREREQUISITES

- Government interested in forming BIORED Teams;
- National Laboratories willing to support BIORED;
- The qualified personnel needed to constitute BIORED Teams.

E. FINANCIAL REQUIREMENTS

The staff required to successfully carry out the work programme outlined above will consist of:

- two senior scientists or technologists;
- eight junior scientist or technologists;
- seven post-doctoral fellows;
- twelve technicians.

It is expected that in the five years twenty trainees will receive formal training in biotechnology.

The Centre will provide the equipment necessary to carry out the activities of this work programme. The required equipment is in Annex I.

Five-year Budget

STAFF		(US$ thousands)
(first year 40 per cent, second year 60 per cent of full operation)		
Senior scientist	8 man year	600
Junior scientist	32 man year	1,440
Post-doctoral scientist	28 man year	672
Technicians	48 many year	816
Subtotal		3,528
Management of the Centre and Supporting Personnel		937
Total Staff		4,465
OPERATIONAL ACTIVITIES		
Visiting scientists	68 man months	480
Expert group meetings	4	100
Advisory services	45 man months	450
Training	40 man years	900
Information material		45
Purchase of Chemicals, etc.	108 man unit years	1,620
Associateship		150
Miscellaneous (travel, telephone, etc.)		138
Total Operational Activities		3,883
Total Work Programme		8,348

ANNEX I

EQUIPMENT REQUIREMENTS

A. BIORED

BIORED use will be:

1. Self-contained in the sense that it should satisfy its own needs for electricity, steam, compressed air and refrigeration (diesel generator and electrical compressor, oil-heated boiler and heat exchanger for evaporative cooling);

2. Capable of grinding, sieving, extracting, boiling and filtering raw materials and of separating microbial cells from liquid media. This equipment would be selected with special reference to the possibility of translating the results obtained into equipment that is appropriate for local use (bamboo tubes, containers of sisal cement or ferrocement, filters of coconut husk, etc.). Centrifugal separation would only be used on a small scale for demonstration and training purposes;

3. Easily transportable: This would limit the size of the fermenters so that they would yield useful results without becoming cumbersome (3 x 10 and 1 x 150 litres stirred reactors and on 75-litre tower fermenter designed both for liquid cultures and for use as an immobilized cell column). In addition there would be one 100-litre media preparation vessel which could also be used for anaerobic cultures or as an incubator for semisolid fermentations.

The equipment mentioned (except the three small fermenters) would be designed to be carried on a open trailer that could be pulled by a four-wheel drive diesel truck. This would carry the service equipment mentioned under 1 above. The 10-litre fermenters would be housed in an air-conditioned trailer laboratory that would also contain an incubator, a refrigerator and a temperature-controlled shaker table. The instrumentation needed for running all the BIORED equipment would be located in the trailer, which would also accommodate two bunks for the support staff. The laboratory trailer would be provided with telecommunications equipment, as would also its pulling vehicle, a large diesel jeep. In addition, this would satisfy the general transportation needs.

Besides supporting research and training activities aimed at such things as the production of seed inoculants, dairy starters, etc., in liquid culture, the BIOREDs should also be equipped with easily transportable materials such as bag digestors for biogas production. In addition, the equipment should include design drawings and audiovisual aids as well as tools and materials for building various devices like plastic-lined ponds (for producing clean water), reflectors (for solar sterilization of media and for the drying of materials) as well as different types of enclosures for semisolid fermentations, mushroom cultivation, etc.

A wide range of processes that deserve attention have been outlined by C. Seshadri and his group at Madras (3) with reference to applied photosynthesis, and by K. Steinkraus (4) in relation to food fermentations. In addition, the review "Microbial Processes: Promising Technologies for Developing Countries", published by the United States Academy of Sciences (5), and the newsletters distributed by the International Mushroom Society for the Tropics (6) deserve careful study in the course of planning individual BIORED missions.

B. EQUIPMENT FOR ADVANCED BIOTECHNOLOGY AND PILOT PLANT

Equipment

- Standard laboratory equipment (microscopes, incubators, refigerators, centrifuges, gas chromatographs, fraction collectors, spectrophotometers, etc.);
- Ten fully instrumented small-scale (10-15 litre) fermenters, mobile, for use outside the biotechnology department;
- Stock of industrial type glassware.

Pilot Plant

- Carbon ring and standard compressors;
- Steam generator;
- Fermenters, including filters, valves and other fixtures:
  one 100-litre unit,
  one 1000-lite unit,
  one 5000-litre unit;
- Storage and precipitation vessels;
- Continuous media sterilizer;
- Harvesting equipment;
- Drying equipment;
- Pipes, platforms, telfers, etc.

Safety Section

- Special safety features (ventilation, sewage, etc.):
- Fermenters, including filters, valves and other fixtures:
  one 100-litre unit,
  one 500 -litre unit,
  one 1000-litre unit;
- Equipment for harvesting and cell disruption;
- Equipment for product recovery and purification.

Control Section

- Gas chromatograph/mass spectrometer;
- Three mobile O_2 and CO_2 units;
- Other standard instruments;
- Standard instrumentation (calorimetry, fluormetry, nephelometry, autoanalysers, etc.);
- Computer.

ANNEX II

FORMAL EDUCATION IN BIOCHEMICAL ENGINEERING

(a) Aims

The ICGEB should produce two types of expert bioengineers: genetic engineering and biochemical engineers. Needless to say, their training would partly overlap, so that a developing country that would have to build bioengineering "from scratch" could initiate an infrastructure around either of the two types of expert.

In the following section only the training of biochemical engineers will be considered. This is done against the background of IUPAC's 1974 "Recommendations on Education in Biochemical Engineering" (12). This presupposes a four-year academic training which should begin with fundamental studies at the undergraduate level, and it accommodates students oriented both towards biology and towards engineering.

The ICGEB training should be broad-based and structured in such a fashion that the knowledge gained does not easily become obsolete. The biochemical engineers produced would have to be "jacks of all trades" with a capacity to control, innovate and trouble-shoot in the fermentation industry and to act as consultants on matters as diverse as management of water pollution, design of fermention plants and elimination of hazards in biochemical work. Of course, they might also be called upon to fill university posts, where they would be charged both with education and research.

(b) Background of Students

Obviously the training must be more flexible and individualized than that we see in industrialized countries, where there are many employment opportunities that require specialization in mechanical, chemical, biochemical, food and environmental engineering, etc. For setting the wheels in motion towards such a differentiation, where biochemical engineering is a component, a developing country

might start with undergraduate courses in food technology and then in fermentation engineering and waste/pollution control. This might be followed by an expansion of the same fields with post-graduate courses, including areas such as enzyme engineering and biomedical engineering. The way would thus be paved towards an indigenous academic and industrial research capability, but since this is inadequate in most poor countries they are more likely to use returning ICGEB trainees as crystallization nuclei for further development.

An adequate training in bioengineering requires knowledge from three basic disciplines: chemical engineering, biochemistry and microbiology. However, without a foundation in reaction kinetics involving microorganisms, biochemical energetics and microbial conversion processes, the translation of various mathematical representations into strategies for controlling biosystems is extremely difficult. Consequently, most graduates from developing countries need a supplementary training where their basic analytical skills are developed and where they learn to think in terms of systems and unit processes.

The focus of their basic training might vary, but in most cases chemical engineering would have been the starting point for a supplementary education in biochemistry and microbiology and for gaining some industrial experience. Most students would consequently come from engineering colleges where undergraduate courses of a year or so would have provided the basic knowledge of general chemistry, physics and mathematics. The graduate training might have started with a year of physical chemistry, organic chemistry, chemical engineering, statistics and computer science supplemented with some basic courses in microbiology. In a third and fourth year there might then have been a focus on practically significant studies of heat transfer, mechanical operations, kinetics and instrumentation and on a minor, experimentally oriented, individual project.

Ideally, the students would come from universities where biochemical engineering was emerging through courses in food technology covering thermal death and chemical activities of microorganisms as an introduction to an overview of the fermentation industry.

However, ICGEB should also be prepared to accept students who had gone through college with an orientation towards medicine and the life sciences, provided and they had supplemented their physics and chemistry with a solid base in mathematics.

In summary then, acceptance for ICGEB postgraduate training would presuppose a four-year academic education starting with fundamental subjects at an undergraduate level followed by differentiated studies oriented either towards engineering or towards the life sciences.

(c) ICGEB Postgraduate Programme in Biochemical Engineering

Students with an adequate background in microbiology, genetics, biochemistry, organic chemistry and chemical engineering might be considered for a 1-2 year postgraduate fellowship programme at institutions associated with ICGEB. The training of the student would then be planned and a thesis topic selected in a dialogue with ICGEB and an associate institution. Both basic and applied projects would be selected (1:1). The associated institution would assume the responsibility for granting degrees.

Since the training would be individualized there is no point in presenting a curriculum, but reference should be made to the courses already offered at the Biological Research Centre of the Hungarian Academy of Sciences (Szeged) and at the International Centre of Co-operative Research and Development in Microbial Engineering, Japan (Osaka). Also, note should be taken of the experience gained in the early 1970s from the "Brazil Chemistry Program". This was an experiment in postgraduate research and training that is highly relevant to the ICGEB's impact aims.

There is for instance every reason to emphasize that ".... overseas Research Fellows need special help in locating new positions when they return home. Provision should be made for travel grants and other devices after the programme is finished to make possible ongoing scientific collaboration among scientists of the participating countries" (13).

The observation that "developing countries with strong capability in a particular discipline might usefully form a linkage with another developing country that happens to have relatively less strength in the chosen field" should also be noted in the planning of individual training programmes.

A start would be made with advanced training in the disciplines that provide the scientific basis of fermentation technology (biochemistry, microbial physiology and genetics). This would be followed with a certain specialization depending on the student's aptitude and ought to include some industrial experience. There would either be an industrial orientation, with an emphasis on process design and economics, or the aim would be set for a regular academic career. Both lines would qualify for advanced doctoral training at ICGEB.

(d) Research Training at ICGEB

The doctoral and post-doctoral training at ICGEB should be informal and based on internal seminars and on lectures and demonstrations by invited specialists. The student should finish the thesis that he had initiated at the associated institution that would eventually grant him a degree. He should gain broad laboratory experience through an individual programme that would rotate him through all ICGEB departments over a period of a few years. The operation of fermenters, biochemical reactors and product recovery equipment would be emphasized, and periods of work in the support (media kitchen) and maintenance facilities (workshop) would be obligatory.

The training would also include exposure to mission-oriented case studies selected to illustrate those problems of design and process engineering that a bioengineer would face when called upon to initiate, plan and implement projects in developing countries. Emphasis would for instance be given to problems related to the utilization of data banks and other sources of information, to the management of technology transfer and licensing, and to the principles that govern the policy with regard to microbiological patents in various countries.

(e) The Alumni Programme at ICGEB

Every effort should be made to maintain the links between ICGEB and the experts which the Centre had trained and between the various "growing points" which the alumni may have established in developing countries. At their disposal the Board of Scientific Directors should consequently have a fund from which, once a year, they could distribute travel grants for this purpose to the alumni.

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